The Gamma Stirling Engine

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Consider the Stirling cycle as shown in figure 1. Read the legend of the figure to identify the key components.

The crucial stage for getting power out is *(b)*. Here the power piston is pushing against the flywheel, increasing its speed. This part of the cycle is called the power stroke; it makes the engine produce its power.

Note that most of the air in the displacer cylinder is red hot. That makes it want to expand, raising the pressure way up. (Since the air can easily move around the displacer piston, the cold air is at the same high pressure as the hot one. OK, if you insist, there is *some* resistance in flowing around the displacer through the regenerator stuff. But that should be small. Sometimes students mistakingly think that the hot air is at high pressure and the cold air at low. But that is not possible because there is no physical barrier between the two to support such a pressure difference. At any given stage in the cycle, it is only the density and not the pressure that is different for the hot and cold air.) The high pressure pushes forcefully against the power piston, and so on the attached flywheel, increasing the flywheel's velocity and kinetic energy. So the device is producing power.

The bad news is the later stage *(d)*. Here the piston is going the other way. Now the flywheel must compress the air again, which slows it down. This stage is called the compression stroke. However, note that now almost all the air is cold. So the pressure slowing the flywheel down during the compression stroke is not by far as large as the pressure speeding it up during the power stroke, That ensures that the power lost during the compression stroke is a lot less than the power generated during the power stroke. So there is a *net* production of power.

It is the displacer cylinder that ensures that there is almost no hot air during the compression stroke. It does that by positioning itself in the hot end of the displacer cylinder, displacing the air that would otherwise be there. During the power stroke, on the other hand, the displacer gets out of the way and so allows the air to enter the hot end, where it then gets heated by the flame at that end.

Note that in stage *(c)* the displacer is moving into the hot air, causing hot air to flow around it through the regenerator at its side, causing the regenerator to pick up heat. Later in stage *(a)* the displacer is moving into the cold air, causing cold air to flow along it through the hot regenerator, so the cold air picks up heat. This heat does not need to come from the flame, so the efficiency is improved. That is how regeneration works.

The theoretical Stirling cycle is, of course, only a very crude approximation of what is going on in figure 1. Still, the middle of the power stroke shown in stage *(b)* corresponds

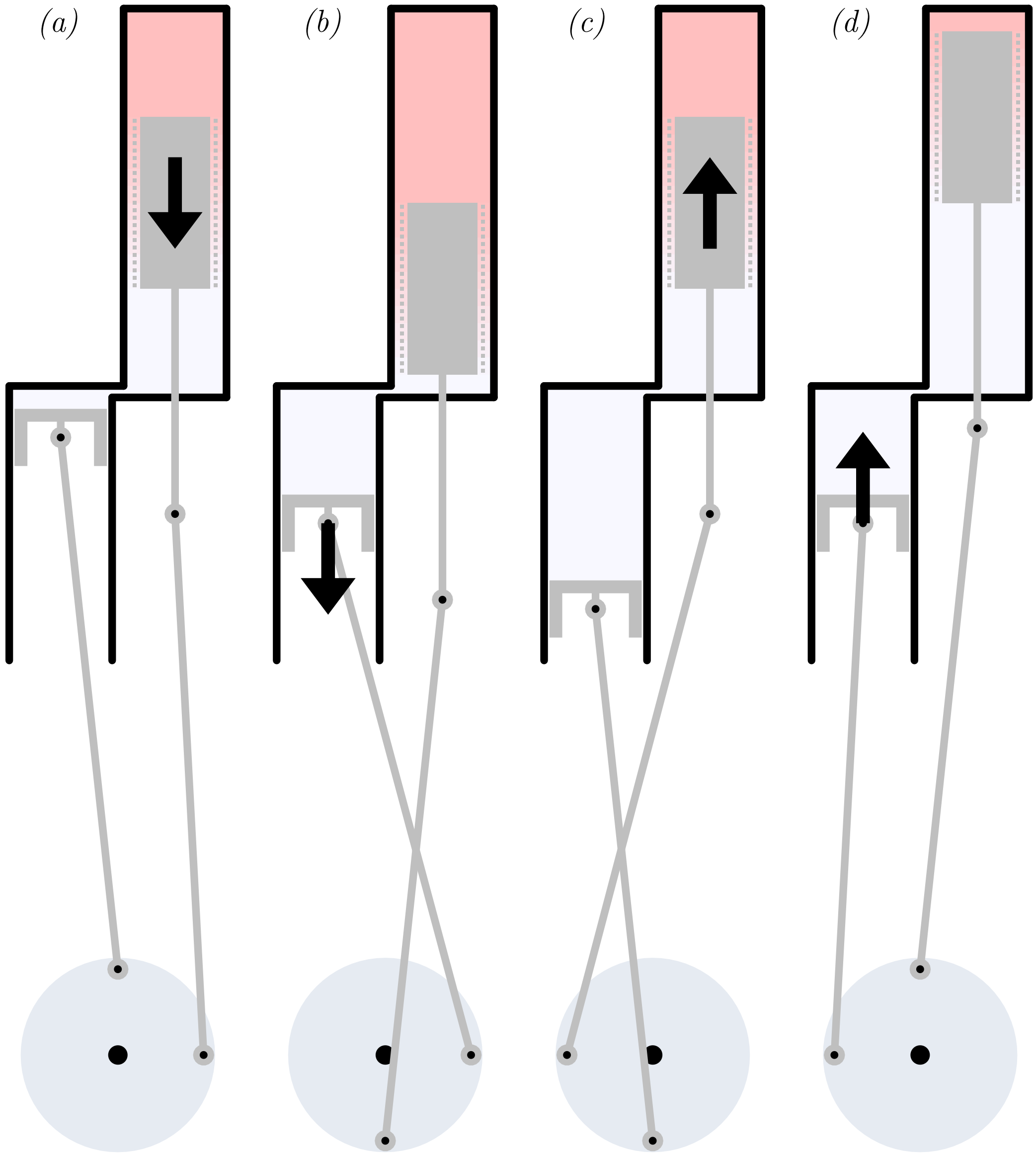

Figure 1: Operation of a Stirling engine. Four equally spaced stages in the operational cycle are shown. In each shown stage, the power cylinder is left and the displacer cylinder is right. The light red color indicates air that is hot; this is because the displacer cylinder is heated at its highest part. The fat arrows indicate the velocity of the power piston (closing off the power cylinder left) or the displacer (inside the displacer cylinder right). The flywheel on the crankshaft is at the bottom. The dots around the displacer represent steel wool or similar that acts as the regenerator. It can absorb heat from the hot air that flows through it in (c), and add that heat later to the cold air that flows through it in (a).

to the middle of the high temperature isothermal part of the theoretical cycle. Note that the displacer cylinder is momentarily at rest here, so is no longer moving additional air to the hot side. That makes the average temperature about constant (assuming good heat conduction). The same way, stage *(d)* corresponds to about the the middle of the low temperature isotherm of the theoretical cycle.

Stage *(a)* corresponds roughly to the middle of the low-volume isochore in the theoretical cycle. The net *total* volume is momentarily constant at its minimum value, as the power piston is at rest at its “top dead center” (TDC) position. And the displacer is heating air by moving it into the hot side. Similarly, in stage *(c)*, at “Bottom Dead Center” (BDC), the net volume is momentarily constant at its maximum value and the displacer is cooling the air by pushing it out of the hot area to the cold side where it can cool down.

Some other misconceptions to avoid may be mentioned. One common proposal by students is to change the working gas. *If you compare different gasses, make sure to compare them at the same number of molecules, not the same mass.* For equal temperature and pressure, different ideal gasses have the same number of molecules, *not* the same mass. (And the mass of the gas is negligible anyway, compared to the engine metal.) So work on a molar basis, not on a mass basis. Check your units!

If you want to study the effect of changing temperature and/or pressure, do that separately, without changing the gas at the same time. Change one thing at a time.

An other thing to keep in mind: as long as the machine is ideal, including regeneration, whatever gas you use makes *zero* difference. The efficiency is then always the Carnot efficiency $(T_{\mathrm{H}} - T_{\mathrm{L}})/T_{\mathrm{H}}$, whether you use air molecules, or small and light helium molecules, or big and heavy and radiactive Radon molecules, or hydrogen sulfide because you like the smell, or two-phase water. So if you propose another substance, you must explain why it would be better even though in the ideal machine it would *not* be any better at all.

Another common proposal is to cool the cold side, say with ice cubes. *If you do so, you must include the freezer and its power requirements in your efficiency.* Remember, the *combined* machine of engine and freezer still takes in heat at the hot side and dumps it to the environment at 20°C. Cheating and ignoring that it cost energy to cool the cold side or make ice cubes is not allowed.